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BRAIN MOTION DURING CONSTANT FREQUENCY HEAD VIBRATION

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INTRODUCTION

The project was undertaken for the following purposes:

- 1) to determine the motion of the brain relative to the skull during constant frequency vibration;
- 2) to determine the resonant frequency or frequencies of the brain;
- 3) to determine the differences between live anesthetized and cadaver animal models with respect to brain responses to vibration;
- 4) to provide some experimental data to assist in the validation of the Finite Element Model of the Brain which was developed by Dr. Ward of the Navy Civil Engineering Laboratory.

EXPERIMENTAL DESIGN AND METHODS

To determine brain motions in an animal model, two techniques could be used. The first would utilize a lucite calvaria to permit high-speed light photography of the brain surface during vibration (1). This technique, however, necessitates the removal of a portion of the skull with its underlying attachment points between the inner table and the brain meninges. Removal of these attachments may be expected to increase the apparent brain motions. In addition, this technique is restricted to the analysis of motion of the cortical surfaces whereas deep brain motion remains undefined.

An alternative technique would involve the implantation of radiopaque pellets within the brain, and detection of their motion with a cinefluorograph (2). With this technique, minimal skull-to-brain surface disruption is achieved by making small openings in the skull to permit insertion of the pellets. To insure that pellet motion is indicative of brain motion, the pellets must be of a density similar to brain tissue, and yet sufficiently radiopaque to permit detection with a cinefluorographic system.

The second technique has been chosen for this project. The isodense-radiopaque spheres were constructed of hollow lead-glass approximately 2 mm diameter (developed by Mr. L. Thiebault of BEIB/NIH).

The animal model selected for these studies was the cynomolgus monkey (*Macaca fascicularis*). Chloralose anesthetized animals were placed in a stereotaxic apparatus for implantation of the head markers. Three to five isodense radiopaque spheres were placed one cm below the outer skull surface along a line running parallel and 7.5 mm lateral to the sagittal suture. Lead pellets (~ 2 mm diameter) were placed within the skull along the same line to serve as reference markers. This arrangement was chosen in order to permit the analysis of overall cerebral hemisphere motion as well as any differential regional brain motions during vibration. The lateral alignment was chosen to avoid penetration of the sagittal sinus during sphere implantation. Anatomically these spheres are lying in either gray or white matter of the

frontal cortex, except for the most posterior sphere which lies in the parietal cortex.

The skull openings were then sealed with a thin layer of bone wax to approximate the inner skull surface. The entire area was then covered by dental acrylic to secure the lead pellets which were placed within depressions in the skull surface.

The animal was placed in a supine position with the head secured into the vibration assembly helmet (Figure 1) as is shown in the X-ray in Figure 2. In this particular experiment, two isodense spheres were placed 1 cm below the skull surface, the third sphere, located at 0.0 (A.P. coordinate), is not isodense because it contains a small lead wire to enhance the radiopacity of the sphere. Skull markers include 4 lead pellets located above the brain spheres as well as two lead markers (#3 and #5 reading from top to bottom in the photograph) which were implanted within the skull wall on the sagittal suture line.

Prior to vibration electrocardiogram leads and a pressure transducer were connected to the animal to permit recording of a Lead-II ECG, systemic blood pressure, and heart rate during vibration.

The vibrator used in this study is a Shore Western model which has a frequency range of 1 to 35 Hz. The stroke of the vibrator piston varies with frequency from a maximum of 2.5 inches at 1 to 3 Hz to a minimum of 0.5 inches at 30 to 35 Hz. Preliminary analysis of cinefluorographic data indicates that the vertical displacement of

the skull at the bregma ranges from a maximum of one cm at 1-3 Hz to a minimum of two mm at 30-35 Hz.

The cinefluorograph system (3) as shown in Figure 1 consists of a Field Emission X-ray generator, the output of which passes through the subject and is detected by a Varian image intensifier whose output is then photographed by a Photosonic's 16 mm high-speed camera. In this project a 350 KVP X-ray source is utilized (50 nsec pulse duration) with a pulse frequency of 400 per second. The entire system is integrated so that the camera shutter opening triggers the X-ray pulse. After completing a vibration series, the animal is euthanatized, and placed in a refrigerator for 24 hours. The next day the animal will then serve as a model for studying the relative brain motions in fresh cadavers.

RESULTS

In a series of preliminary studies lead pellets (2 mm diameter) were implanted within the brain as well as on the skull surface. These experiments demonstrated that the brain marker motion relative to skull surface increases with vibration frequency, and reaches maximum relative motion at 20-25 Hz. These findings, however, are not truly indicative of brain motion because the brain markers were lead, which is approximately 20 times more dense than brain tissue. We have just

completed out first experiments utilizing the isodense radiopaque sphere and the films are undergoing digitization.

Physiological recordings gathered during the preliminary experiments indicate that vibration failed to alter any of the cardiovascular parameters.

Proposed Experiments

After completion of the initial study, the sphere implantation procedure will be modified to study the magnitude of motion which occurs as distance from the center of rotation is increased. Spheres will be implanted at the center of rotation and at 1 cm increments up to the skull surface.

If differences are observed between live-anesthetized and 24-hour cadaver animals, this study may be expanded to include animals studied 49-120 hours after sacrifice.

References

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3. Shatsky, S. A. Flash x-ray cinematography during impact injury. Proceedings of the 17th Stapp Car Crash Conference, p. 51, New York: Society of Automotive Engineers, Inc., 1973.

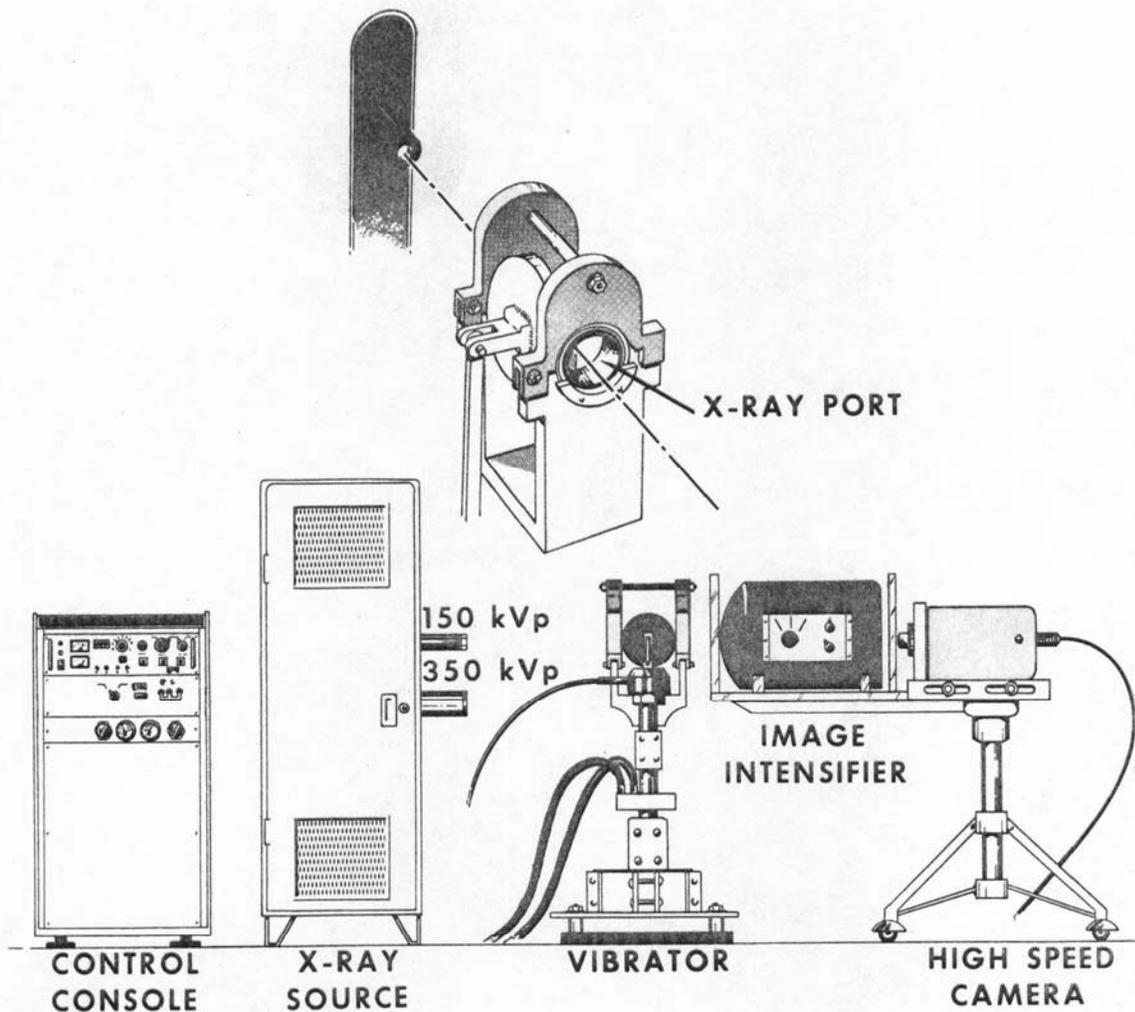


Figure 1. Experimental equipment for analyzing brain motion during vibration. The high-speed cinefluorograph system consists of a Flexitron flash x-ray unit, Varian variable-zoom image intensifier and Photosonics 16-mm pin register camera. The unit is coupled such that the opening of the camera shutter triggers the x-ray pulse. The vibration assembly consists of a Shore Western vibrator with attached linkage and helmet for securing the animal's head. The port through the helmet permits the passage of x-rays through the subject.

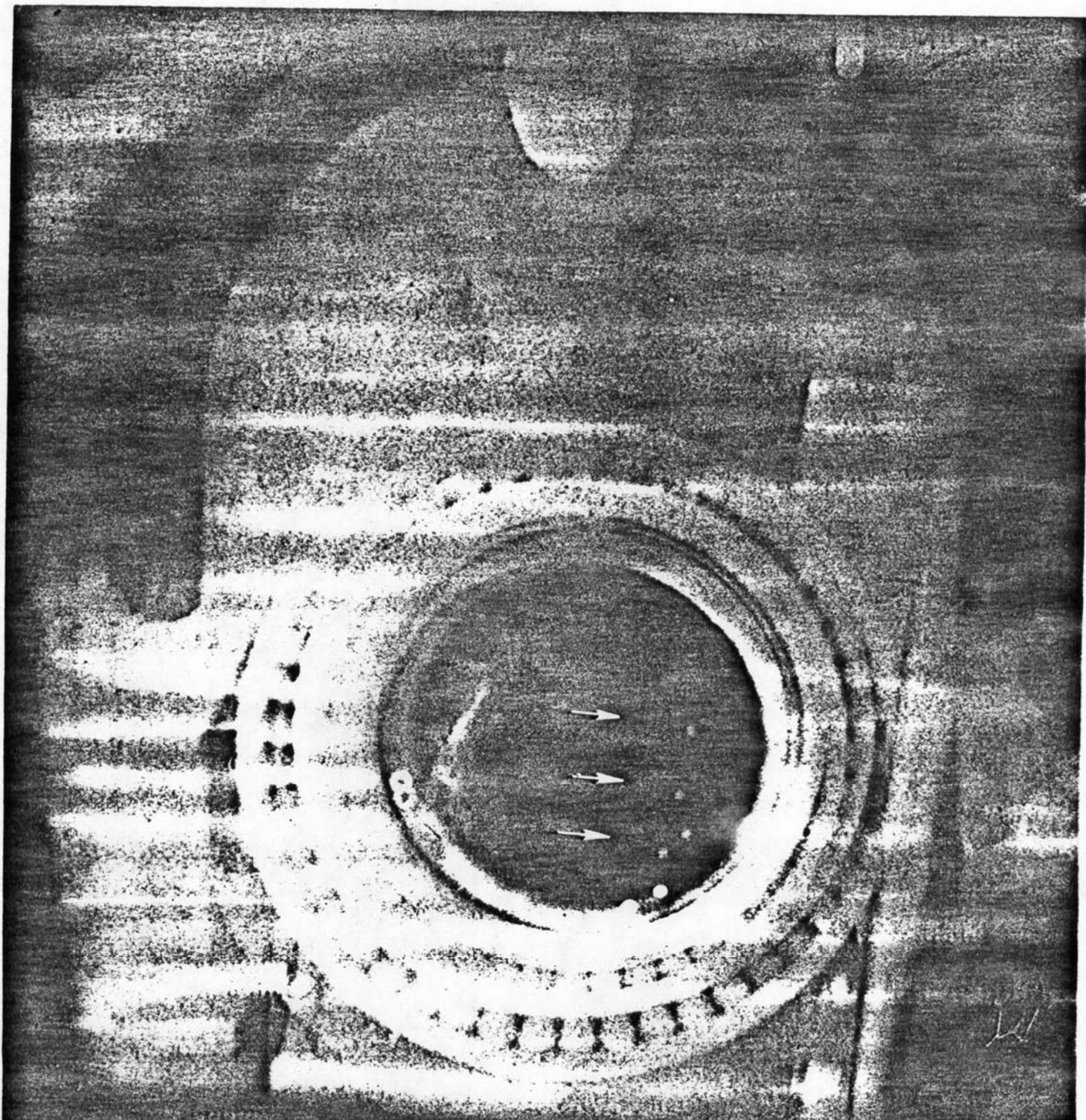


Figure 2. X-ray plate showing the monkey head secured in the vibrator helmet. The animal is oriented face up. The six lead pellets in the skull can be seen as well as the three isodense radiopaque spheres in the brain tissue (the lowermost sphere has a lead wire inside to improve its opacity).